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Theories of Expertise as Models for Understanding Situation Awareness

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Abstract

Situation awareness is often understood as a skill unique to piloting aircraft and controlling other real time processes. Research intended to better understand or to measure situation awareness, however, has proven to be difficult. An alternative approach to investigating situation awareness is proposed using theories of expertise as models. These theories provide a mechanism which explain why pilots will maintain or fail to maintain situation awareness. Further, models based on theories of expertise provide testable hypotheses regarding quantifiable aspects of situation awareness and suggest training interventions to improve situation awareness.

Situation awareness is a term used by pilots and other operators of real-time processes to describe the operator's, "knowledge about his surroundings in light of his mission's goals," (Whitaker & Klein, 1988, p. 321). The concept is most often used to explain performance failures. A pilot who for no discernable reason does not respond to a threat such as an enemy aircraft or the ground, is said to have failed to maintain situation awareness. Cognitive psychologists have rapidly embraced the concept of situation awareness even though a workable definition is elusive (Fracker, 1988; Sarter & Woods, 1991).

Although the concept of situation awareness is undoubtedly useful, cognitive psychologists are experiencing great difficulty in defining the term and applying it to research. A major source of this difficulty is that situation awareness has no grounding in cognitive theory or previous research. Situation awareness is a pilot's concept used to explain why things go wrong. Applying empirical research tools to what is an intuitive concept has failed to shed much light on questions such as: what are the mechanisms for maintaining situation awareness, what are the variables which will allow one person to maintain situation awareness while another will not, is maintaining situation awareness a mental skill or ability by itself or is it the result of other cognitive skills? Attempts to understand situation awareness by directly studying pilots and other real-time process operators have thus far produced mixed results.

An alternative approach to understanding situation awareness is to review existing research and theory in cognitive psychology to identify phenomena which display the same characteristics as situation awareness. These phenomena can then be used as models to explore situation awareness and to understand the cognitive processes involved in maintaining or losing situation awareness. With this understanding, researchers will be better able to devise and validate training interventions to reduce the incidence of performance failures due to loss of situation awareness. One phenomenon which may serve as a model for understanding situation awareness is the study of expertise. Expertise can be defined as the ability to perform demanding tasks rapidly and error-free; compared to the expert, the novice's performance is

slow, effortful, and prone to many errors (Anderson, 1983). Given that performance failures are often attributed to the loss of situation awareness, expert-level performance may be the equivalent to maintaining situation awareness for a highly demanding task. A review of the literature demonstrates that there are many similarities between situation awareness and expertise. Further, the extensive body of theory on expertise can shed significant light on the mechanisms of situation awareness and can provide many opportunities for research and development of training systems to improve situation awareness.

Comparison of Situation Awareness to Expertise

Endsley (1990) reported research on situation awareness in which pilots flew a series of simulated, tactical air-combat missions. In Endsley's studies, "At some random point in time the simulation is stopped and the cockpit and out-the-window displays are blanked. The pilot is asked a series of questions in order to determine his knowledge of the situation at that exact moment in time," (p. 42). Endsley found that ability to recall the location of other aircraft in the simulation was significantly related to mission success. Endsley's research on tactical pilots is highly reminiscent of a landmark series of studies on chess expertise conducted by Chase and Simon (1973). Chase and Simon found that the most successful players (experts) were able to recall the position of chess pieces on a briefly presented board while less successful players (novices) were not. The experts' ability to recall board position, however, was no greater than the novices' if the chess pieces were positioned at random. Chase and Simon assert that the experts' ability to rapidly encode and store positions resulted from their ability to recognize configurations and patterns among the pieces. Information available in the experts' long term memory allowed them to encode the chess board positions as a small set of interrelated configurations (i.e., "chunking") rather than as a large set of individual positions. Similar results have been found in comparisons of expert vs novice bridge players (Engle & Bukstel, 1978) and baseball fans (Chisi, Spilich, & Voss, 1979). Charness (1989) concludes from these results that changes in encoding speed and chunking efficiency support a hypothesis that increases in skill result from increases in the number of stored patterns in the expert's knowledge base and a significant increase in the expert's ability to access this knowledge. Feigenbaum (1989) goes further to summarize these and other findings as the knowledge principle:

> A system exhibits intelligent understanding and action at a high level of competence primarily because of the specific knowledge it can bring to bear: the concepts, representations, facts, heuristics, models, and methods of its domain of endeavor. (p. 179).

Klein, Calderwood, and Clinton-Cirocco (1986) interviewed 26 midwest fire captains regarding the manner in which they establish situation awareness when arriving at a fire. All of the officers were highly experienced with a mean of 23.2 years as firefighters. Klein et al determined that decisions were made very quickly, less than one minute, in 78% of the cases studied. Most of the longer decision times were associated with a fire at a gas and oil storage complex. In this case, "the local firefighters who tried to contain the blazes could not be considered experts. They had no experience with a fire of this magnitude or with many of the specific problems encountered," (p. 557). Klein et al categorized each of 156 decisions as reflecting either a deliberated process in which the officer evaluated alternative approaches or

a prototype match process in which the officer assigned the fire to a specific category based on experience. Evidence of deliberative process was found for only 19% of the incidents and half of these came from the storage complex fire. The remaining decisions were made by rapidly matching the fire to a stored prototype. The fire captains then refined their mental model of the fire based on perceptual cues. In sum, Klein et al found that experienced fire captains under time pressure used their knowledge base of prototype fires to establish situation awareness.

Researchers studying situation awareness have stressed the need for pilots to rapidly encode and understand the significant events occurring in the environment (Sarter & Woods, 1991). Researchers studying expertise have found that these are the abilities which characterize expert level performance. Further, research has demonstrated that expertise is based on rapid access to an extensive knowledge base of domain specific information. The expert identifies the present situation as an example of a familiar prototype and selects a response accordingly. Fracker (1988) asserts that an identical mechanism is responsible for situation awareness: "Matched knowledge structures...provide the pilot's assessment of the situation and serve to guide his attention," (p. 102).

Skilled Memory as a Model for Situation Awareness

The theory of skilled memory has been proposed by Chase and Ericsson (1981) and Ericsson and Stazewski (1989) to explain the cognitive mechanisms responsible for expert level performance. These authors assert that expertise is domain specific, requires long practice, and frequently involves a mnenomic encoding strategy. From the study of experts in several domains, they postulate three principles of skilled memory.

1. "Experts use their knowledge structures in semantic memory to store information during skilled performance of some task," (Chase and Ericsson, 1981, p. 159).

2. "Expert memory involves organized and direct retrieval from long term memory," (p. 175). The two corollaries to this second principle are that experts know when to apply knowledge to a problem and that experts store intermediate knowledge states for future reference in directly accessible long term memory.

3. As memory skill increases, the time required to encode and retrieve task relevant information decreases (p. 184).

The theory of skilled memory asserts that experience in and of itself is not sufficient to produce expertise. Rather, the journeyman who is gaining experience is also learning to encode the significant elements of a given situation into a knowledge structure. The encoding process is self-addressable in that the associations used to encode a situation into a given knowledge structure also are the retrieval cues used to recall the information when a similar situation is encountered (Ericsson and Stazewski, 1989, p. 239). With experience, the journeyman learns to access the appropriate knowledge structure and abstract the relevant features. This process gets faster with experience until it appears to be automatic. Equating situation awareness with application of skilled memory provides several testable hypotheses about situation awareness and suggests opportunities for developing training interventions.

Implications of Skilled Memory Theory for Understanding Situation Awareness

1. Maintaining situation awareness is the product of expertise and not an independent skill or mental ability. Training designed to increase situation awareness directly will be fruitless. Training must be designed to increase the breadth and depth of the pilot's skill in tactical situations.

2. Situation awareness and expertise are specific to a knowledge domain. Pilots will have difficulty maintaining situation awareness in an unfamiliar tactical environment. Training which provides experience for unfamiliar events will be highly effective in improving a pilot's ability to maintain situation awareness. Houck, Thomas, and Bell (1989) conducted simulated, multiplayer air combat training exercises. Participants in these exercises were mission-ready F-15 pilots and air weapons controllers. For many tasks, participants rated the multiplayer, air-combat training as both valuable for increasing mission success and superior to the training received in the aircraft. Notably, these tasks were relatively unfamiliar because they are rarely practiced in the aircraft due to safety, security, and cost restrictions: tactics against four or more bogeys, chaff and flare employment, electronic countermeasures, all-aspect defense and, work with air weapons controllers. Tasks which are practiced in the aircraft were rated as not having significant training need: tactical formation, visual lookout and, basic fighter maneuvers. Based on skilled memory theory, it is hypothesized that a pilot's ability to recall events from a multiplayer air combat sortie will increase with increasing experience in similar engagements. Further, increasing ability to recall events will be correlated with increasing ability to maintain situation awareness and ultimately to increasing combat success.

3. The effectiveness of simulator-based training will be greatly increased by instructional support in assisting participants to understand, interpret, and encode the situations, actions, and results of simulated engagements. This assistance must be provided by more experienced pilots supported by well designed mission planning and debriefing tools.

The Aircrew Training Research Division of the USAF Armstrong Laboratory is currently developing the capability to support multiplayer, air combat simulation. Research will be conducted at Armstrong Laboratory to identify training strategies which will improve combat skills for tactical pilots including the ability to maintain situation awareness. Using existing cognitive theory and research as models for problems of interest to combat pilots will support the effective development of training procedures to improve combat readiness.

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